SEISMIC HAZARD ZONE REPORT 073

SEISMIC HAZARD ZONE REPORT FOR THE PITAS POINT 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Pitas Point 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 13 square miles at a scale of 1 inch = 2,000 feet.

The land portion of the quadrangle is mostly deeply dissected mountainous terrain bordering the Pacific Ocean in western Ventura County. Rincon Point, the westernmost land in the quadrangle is about 13 miles northwest of the City of Ventura along U.S. Highway 101 (Pacific Coast Highway). Small, rural communities of La Conchita, Seacliff, and Faria Beach are located along the coastline in this unincorporated area of Ventura County. Narrow beaches line the entire coastline. Highway and railroad transportation routes and the settlements are located upon a narrow terrace that is backed on the landward side by steep cliffs and mountainsides. Remnants of several gently sloping marine terraces are located at various elevations above the sea. Numerous deep canyons dissect the mountains. Elevations within the quadrangle range from sea level to 2,161 feet on Rincon Mountain. The Rincon, Padre, and the western portion of the San Miguelito oil fields are located in the quadrangle. The coastal and beach areas are used for residential, recreation, transportation and petroleum purposes. Elevated, sloping terraces above La Conchita are primarily developed for agriculture.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

In the Pitas Point Quadrangle the liquefaction zone is restricted to the beach, the low-relief aprons between the beach and the base of the cliffs and the bottom of Padre Juan Canyon and Los Sauces Creek. The combination of deeply dissected mountainous terrain in weak Tertiary sedimentary rock units in an area that has experienced intense deformation in the recent geologic past has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 75 percent of the land area within the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Pitas Point 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Pitas Point 7.5-Minute Quadrangle, Ventura County, California

By
Ralph C. Loyd and Allan G. Barrows

California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Pitas Point 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles region was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, including areas in the Pitas Point Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Pitas Point Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The onshore portion of the Pitas Point Quadrangle covers approximately 10 square miles of mostly mountainous terrain bordering the Pacific Ocean in western Ventura County. Rincon Point, the westernmost land in the quadrangle, is on the Ventura County Santa Barbara County boundary and is about 13 miles northwest of the City of Ventura along U.S. Highway 101 (Pacific Coast Highway). The small communities of La Conchita (between Punta Gorda and Rincon Point), Seacliff (between Punta Gorda and Pitas Point), and Faria Beach (at Pitas Point) are located along the coast in this unincorporated area of Ventura County. Richfield Island is a small man-made island with oil wells connected to

Punta Gorda by a pier at Mussel Shoal. Parts of State Highway 1 (Old Rincon Highway) and the Southern Pacific Railroad tracks also parallel the shoreline.

Narrow beaches line the entire coastline. Transportation routes and the settlements are located upon a narrow terrace that is backed on the landward side by steep cliffs and mountainsides. Remnants of several gently sloping marine terraces are located at various elevations above the sea. Numerous deep canyons dissect the mountains. Landslides, debris slides and flows, and earth slides and flows are very abundant within the Pitas Point Quadrangle. The so-called La Conchita landslide of March 4, 1995 destroyed numerous dwellings. Elevations within the quadrangle range from sea level to 2,161 feet on Rincon Mountain, located near the northern boundary of the quadrangle.

Geologic structures in the Pita Point Quadrangle trend northwest-southeast, and are expressed as uplifted folds and faults, which have been eroded into peaks and valleys. There are two major faults in the quadrangle, the Red Mountain Fault and Padre Juan Fault. A major structural feature, the Rincon Anticline, is located between the Red Mountain and Padre Juan faults. Sedimentary rocks within the Rincon Anticline are a significant petroleum source. The Rincon Oil Field, the Padre Oil Field, and the western portion of the San Miguelito Oil Field are located along the Rincon Anticline.

The coastal and beach areas are used for residential, recreation, transportation and petroleum purposes. Elevated, sloping terraces above La Conchita are primarily developed for agriculture. The hilly, middle and southern onshore areas are developed as oil fields, as are some of the nearby offshore areas.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Geologic mapping used in this study was obtained from the Dibblee Geological Foundation (Dibblee, 1988) and digitized by CGS staff for this study. Additional geology reviewed during the study includes a Quaternary geologic map by William Lettis and Associates (2000). The distribution of Quaternary deposits on the Dibblee map was used in combination with other data, discussed below, to evaluate liquefaction potential and develop the seismic hazard zone map. The surficial units are described in this section. Bedrock geologic units are discussed in more detail in Section 2.

Bedrock units of the Pitas Point Quadrangle range from Oligocene to Pleistocene. Except for the Sespe Formation (Tsp), which crops out near the northeastern corner, all of the bedrock units are of marine origin. Pleistocene to Holocene surficial units unconformably overlie the Tertiary bedrock units. Surficial deposits are restricted to areas along active stream channels, elevated terraces, shallow landslides and debris flows, and beach areas. The oldest Quaternary units in the Pitas Point Quadrangle are older marine terrace deposits (Qom), older alluvial deposits (Qoa), and older cobble-boulder fan and fanglomerate deposits (Qog). Younger deposits consist of alluvium in stream and lowland environments

(Qa). Artificial fill (af) has been used extensively along the coastline for road and railroad construction, but is not delineated on the geologic maps examined during this study.

Structural Geology

The Pitas Point Quadrangle is within the Western Transverse Ranges Province of southern California. The Transverse Ranges Province has a predominant east-west structural grain in contrast to the typical northwest grain of most of California. Geologically, this area includes one of the deepest sedimentary structures in the world. The channel region offshore forms the western part of the province, and is the partly submerged extension of the Ventura Basin, a structural depression that contains more than 50,000 feet of Cretaceous and Tertiary strata (Vedder and others, 1969). Structurally, a north-south compression of sedimentary strata, which began in Pleistocene time and continues to the present, caused crustal shortening and warping of the sedimentary fabric into the mostly east-west trending series of anticlinal/synclinal folds present in the study area (Keller, 1988, from Nagle and Parker, 1971; Yeats, 1983; Namson, 1987). As deformation continued, large, north- and south-dipping reverse faults were formed offsetting the rock formations. The compression also affected sediments north of Red Mountain Fault within the Pitas Point Quadrangle and beyond. The largest structural elements in the Pitas Point Quadrangle are the Rincon Anticline and the Red Mountain Fault. In the Pitas Point Quadrangle, the north-dipping Red Mountain Fault and the south-dipping Padre Juan Fault (also known as the Javon Canyon Fault at the surface) divide the area surrounding the Rincon Anticline, into three main blocks.

Since deposition, sedimentary rocks in this province have been complexly folded, faulted, and uplifted, during several periods of deformation and erosion. These folded strata contain numerous petroleum traps. The hilly, middle and southern onshore areas are developed as oil fields (Rincon, Padre Juan, and San Miguelito fields), as are some of the near-shore areas.

Structurally, the area is undergoing deformation including rapid uplift in the recent past, which has pushed up the sedimentary rocks and, concurrently, the Quaternary alluvial veneer to the current elevations. Estimates of the amount of compression and convergence vary from 23 mm/yr (Yeats, 1983) to about 27 mm/yr (Namson, 1987). The intense and ongoing deformation that created the steep limbed folds and faults also created a southward arched curve of structural grain in the middle of the quadrangle. The Rincon Anticline, the largest fold in the Pitas Point Quadrangle, is present offshore at Punta Gorda, and trends southeast onshore. This anticline then turns eastward, and becomes the Ventura Avenue Anticline.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of sedimentary deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. Unfortunately, only 6 logs were found in the files of the Ventura County Water Resources and Engineering Department, Ventura County Hazardous Substances Control

Program, and the California Department of Transportation (CalTrans). Locations of the exploratory boreholes considered in this investigation are shown on Plate 1.2. Staff routinely enter data from geotechnical logs into CGS's GIS in order to create a database that would allow effective examination of subsurface geology through construction of computer-generated cross sections and evaluation of liquefaction potential of sedimentary deposits through the performance of computer-based quantitative analysis. The few boreholes available in the Pitas Point Quadrangle preclude an effective evaluation of the subsurface, but they do provide useful information regarding the general lithologic and engineering properties of the beach and alluvial deposits penetrated.

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

The 6 logs collected in this study all include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. None of the borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

GROUND-WATER CONDITIONS

Depth to ground water is a key factor governing liquefaction hazard. Ground-water saturation reduces the effective normal stress acting on loose, sandy sediments, thus lowering the resistance of sediments to loss of strength when pore-water pressure increases during ground shaking. Liquefaction of subsurface sedimentary layers can result in structure damaging ground failure at the surface through differential settlement or lateral spreading, particularly if the phenomenon occurs at a depth from the surface of less than 40 feet.

Natural processes and human activities over seasons, years, and decades cause large fluctuations in ground-water levels. These fluctuations generally make it impossible to specify what conditions might exist when future earthquakes could cause major ground shaking. To address this uncertainty, CGS develops ground-water maps that show depths to historically shallowest levels recorded from water wells and boreholes drilled over the past century. The evaluations are based on first-encountered water noted in the borehole logs. Water depths from boreholes known to penetrate confined aquifers are not used. The resultant maps, which are based on measurements recorded over the past century or more, differ considerably from conventional ground-water maps that are based on measurements collected during a single season or year.

Historically shallowest depths to ground water in the canyon regions and shore line areas of the Pitas Point Quadrangle are presented on Plate 1.2. As shown on Plate 1.2 historical ground-water levels in canyon areas are, in general, shallow, commonly about 10-foot depth. Such shallow ground-water conditions commonly exist in these types of depositional environments because seasonally, canyon lowlands tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands.

LIQUEFACTION POTENTIAL

Liquefaction can occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and might fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985) who apply a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates following criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. CGS's qualitative assessment of liquefaction susceptibility relative to various geologic units and depth to ground water is summarized in Table 1.1.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qs	Sand	Beach sand	Very loose	Yes
Qa	Sand, silt, clay	Young alluvial fan and valley deposits	Loose to moderately dense	Yes**
Qoa, Qog, Qom,	Clay, silt, sand, and gravel deposits.	Older alluvial and marine terrace deposits	Dense to very dense	Not likely

* When saturated ** Not likely if all clay or if sand and silt layers are clayey

Table 1. 1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

LIQUEFACTION OPPORTUNITY

Analysis of in-situ liquefaction potential requires assessment of liquefaction opportunity. Liquefaction opportunity is the estimation of the severity of expected future ground shaking over the region at a specific exceedance probability and exposure time (Real, 2002). The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis of liquefaction potential is the magnitude that contributes most to the calculated PGA for an area.

For the Pitas Point Quadrangle, PGAs of 0.60g to 0.73g (for alluvium conditions), resulting from a predominant earthquake of magnitude of 6.8 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (section 3) of this report for additional discussion of ground motion characterization.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). The Seed-Idriss Simplified Procedure enables sediment resistance to liquefaction to be calculated and expressed in terms of cyclic resistance ratio (CRR), The procedure is based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading to a M7.5 event. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS

= (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample for which standardized blow counts were collected. Typically, multiple samples are collected from each borehole. The program then calculates an FS for each non-clay layer that includes at least one penetration test. If a layer contains more than one penetration test, the minimum $(N1)_{60}$ value is used. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS values, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil throughout a project area, are evaluated to delineate areas of relative high liquefaction potential. These areas then translate directly to "Zones of Required Investigation."

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Pitas Point Quadrangle is summarized below.

Areas of Past Liquefaction

No recorded accounts of historical or prehistorical liquefaction occurrences were found in this study.

Artificial Fills

In the Pitas Point Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered and non-engineered fill for highway, road, and railroad construction and, to a lesser extent, residential development along the Pacific coast. Much of the artificial fill, especially fill associated with early 20th century road and railroad construction, may not be properly engineered. Non-engineered fills are commonly loose and uncompacted and, therefore, likely to liquefy. Such areas are included in "zones of required investigation. Areas containing engineered fill, including the 1.5-mile long beach widening project between Sea Cliff and Punta Gorda associated with Highway 101 construction, are zoned on other factors.

Areas with Sufficient Existing Geotechnical Data

Only 6 geotechnical borehole logs within the Pitas Point Quadrangle were found during the course of this study. As a result, zones for liquefaction hazards are based principally on criterion number 4 described above.

Areas with Insufficient Existing Geotechnical Data

Shoreline beach deposits. Beach deposits along the Pacific Ocean coastline are composed of loose, saturated sand that is highly susceptible to liquefaction. These deposits, therefore, are included in a zone of required investigation.

Alluvium deposited along base of coastal highlands. Just inland of the beach sands are alluvial, debris flow, and landslide deposits that have accumulated along the base of the coastal mountain front. Although likely to contain an abundance of fine material, these deposits are also likely to contain layers and lenses of silt and sand that are susceptible to liquefaction and are, therefore, included in zones of required investigation.

Canyon floors. Canyons in the Pitas Point Quadrangle containing alluvial deposits are designated zones of required investigations. Geologic mapping by Dibblee (1988) and William Lettis and Associates (2000), indicate that canyon alluvium, where present, is composed mainly of sandy material eroded from adjacent, sandstone-rich bedrock formations (see discussion of rock units in Geology discussion in sections 1 and 2).

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Pitas Point 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the

Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Pitas Point 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Pitas Point Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Pitas Point Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Pitas Point Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The onshore portion of the Pitas Point Quadrangle covers approximately 10 square miles of mostly mountainous terrain bordering the Pacific Ocean in western Ventura County. Rincon Point, the westernmost land in the quadrangle, is on the Ventura County/Santa Barbara County boundary and is about 13 miles northwest of the City of Ventura along U.S. Highway 101 (Pacific Coast Highway). The small communities of La Conchita (between Punta Gorda and Rincon Point), Seacliff (between Punta Gorda and Pitas Point), and Faria Beach (at Pitas Point) are located along the coast in this unincorporated area of Ventura County. Richfield Island is a small man-made island with oil wells connected to Punta Gorda by a pier at Mussel Shoal. Parts of State Highway 1 (Old Rincon Highway) and the Southern Pacific Railroad tracks also parallel the shoreline.

Narrow beaches line the entire coastline. Transportation routes and the settlements are located upon a narrow terrace that is backed on the landward side by steep cliffs and mountainsides. Remnants of several gently sloping marine terraces are located at various elevations above the sea. Numerous deep canyons dissect the mountains and terraces. Landslides, debris slides and flows, and earth slides and flows are very abundant within the Pitas Point Quadrangle. The so-called La Conchita Landslide of March 4, 1995 destroyed numerous dwellings. Elevations within the quadrangle range from sea level to 2,161 feet on Rincon Mountain, located near the northern boundary of the quadrangle.

The coastal and beach areas are used for residential, recreation, transportation and petroleum purposes. Elevated, sloping terraces above La Conchita are primarily developed for agriculture. The hilly, middle and southern onshore areas are developed as oil fields, as are some of the nearby offshore areas.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Pitas Point Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1988) and digitized by CGS staff for this study. A map of the Quaternary (surficial) geology was obtained in digital form from William Lettis and Associates (2000). The bedrock units are described in detail in this section. Surficial geologic units are discussed in more detail in Section 1.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory created during this study would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were also revised based upon comparisons between the two source maps. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of slope failures was noted.

Bedrock units of the Pitas Point Quadrangle range from Oligocene to Pleistocene. All of the bedrock units are of marine origin, except for the Sespe Formation (Tsp), which crops out near the northeastern corner. Surficial deposits are limited to areas along active stream channels, elevated terraces, alluvial and fan gravels, shallow landslides and debris flows, and beach areas.

The oldest exposed unit in the Pitas Point Quadrangle is the predominantly Oligocene non-marine Sespe Formation (Tsp). The Sespe Formation is typically a pinkish-gray to light brown, moderately hard arkosic sandstone, with local interbeds of maroon-red siltstone and claystone. Red claystone is most abundant near the top of the formation. The Sespe Formation is exposed along the east edge of the quadrangle within the core of the northwest plunging Red Mountain Anticline.

Early Miocene, shallow marine transgressive Vaqueros Sandstone (Tvq) conformably overlies the Sespe Formation. In the Pitas Point Quadrangle, Vaqueros Sandstone crops out as moderate to steeply dipping beds on the nose of the Red Mountain Anticline. Vaqueros Sandstone consists of massive to poorly bedded, light gray to tan, fine-grained sandstone and conglomerate, which is locally calcareous.

Early Miocene marine Rincon Shale (Tr) is conformable on the Vaqueros Sandstone and consists of poorly bedded, gray clay shale and siltstone, with occasional gray dolomitic concretions. According to Vedder and others (1969), “zones of bentonite clay occur in the upper and lower parts of the section along the mainland coast.” Rincon Shale is exposed in the northeastern corner of the quadrangle, where it is deformed around the nose of the Red Mountain Anticline and contains abundant landslides.

The early to late Miocene marine Monterey Formation (Modelo Formation), is conformable on the Rincon Shale and has two members exposed in the Pitas Point quadrangle. The lower shale unit (Tml) consists of white-weathering, soft, fissile to punky clay shale, with interbeds of hard siliceous shale and thin limestone strata. The upper shale unit (Tm) consists of thin bedded, hard, platy to brittle, siliceous shale. These units are widespread in a series of southeast-plunging anticlinal and synclinal folds associated with the Red Mountain Fault Zone.

Late Miocene marine Sisquoc Shale (Tsq) is conformable on the Monterey Formation. It is exposed as steeply south-dipping to overturned beds that abut the Red Mountain Fault on the south contact. Sisquoc Shale consists of a light-gray silty shale or claystone, which is locally slightly siliceous and diatomaceous. Sisquoc Shale may also contain layers of tuffaceous sandstone, whose source, according to Vedder and others (1969) was "outside the study area." On the elevated terraces above La Conchita, alluvial deposits cover Sisquoc Shale.

Tectonic forces acting on the Red Mountain Fault and associated unnamed fault segments deformed the geologic units in the Pitas Point Quadrangle. Relative motions on these faults have resulted in the units being raised to the northeast, and dropped on the southwest. Movement on the Padre Juan Fault, on the southern end of the mapped units, has lifted the Pico Formation forming a graben in the middle. According to Nagle and Parker (1971), and Keller (1988) and others, this graben widens with depth.

Pliocene to Pleistocene marine Pico Formation has six members. The oldest is the "Repetto" Member (Tpr), which is mapped in two discontinuous areas in the Pitas Point Quadrangle. The "Repetto" Member consists of gray claystone and contains microfauna of early Pliocene age. The younger, mostly gray, Pico Formation (Tp) claystone is conformable above the "Repetto," and while similar, it is vaguely bedded, and has a few thin strata of sandstone. Interbedded with the Pico Formation claystone are two other members, the Pico sandstone-conglomerate (Tpsc), and the Pico sandstone (Tps). The sandstone and conglomerate member (Tpsc) may also have pebbles and cobbles of hard sandstone. The other interbedded sandstone member (Tps) is a mostly light gray to tan sandstone, well bedded, in some places pebbly, which includes some interbedded claystone. The fifth member of the Pico Formation (QTpmc) is mapped only within the adjacent Ventura Quadrangle and not within the Pitas Point Quadrangle (Dibblee, 1988). The sixth member of the Pico Formation (QTpm) is also known as the Mudpit Claystone Member of the Santa Barbara Formation (Yerkes and others 1987; Yeats and Grigsby, 1987; Grigsby, 1988), and is reportedly of early Pleistocene to possibly late Pliocene age. This member is massive to vaguely bedded, gray claystone or mudstone, and may include the QTpmc member.

Pleistocene to Holocene surficial units unconformably overlie the Tertiary bedrock units. The oldest Quaternary units in the Pitas Point Quadrangle are older marine terrace deposits (Qom, from William Lettis and Associates, 2000, as noted in Section 1), older alluvial deposits (Qoa), and older cobble-boulder fan and fanglomerate deposits (Qog). Younger deposits consist of alluvium (Qa) in stream and lowland environments, beach deposits (Qs), colluvium, and stream wash, and landslide deposits (Qls). Artificial fill (af) also exists within the Pitas Point Quadrangle. A more detailed discussion of the Quaternary units can be found in Section 1.

Structural Geology

The Pitas Point Quadrangle is within the Western Transverse Ranges Province of southern California. The Transverse Ranges Province has a predominant east-west structural grain in contrast to the typical northwest grain of most of California. Geologic structures in the Pita Point Quadrangle trend northwest-southeast, and are expressed as uplifted folds and faults, which have been eroded into peaks and valleys. There are two major faults in the quadrangle, the Red Mountain Fault and Padre Juan Fault. A major structural feature, the Rincon Anticline, is located between the Red Mountain and Padre Juan faults. Sedimentary rocks within the Rincon Anticline are a significant petroleum source. The Rincon Oil Field, the Padre Oil Field, and the western portion of the San Miguelito Oil Field are located along the Rincon Anticline.

Geologically, this area includes one of the deepest sedimentary structures in the world. The channel region offshore forms the western part of the province, and is the partly submerged extension of the Ventura Basin, a structural depression that contains more than 50,000 feet of Cretaceous and Tertiary strata (Vedder and others, 1969). Tectonic forces acting on the Red Mountain Fault and associated unnamed fault segments deformed the geologic units in the Pitas Point Quadrangle. Relative motions on these faults have resulted in the units being raised to the northeast, and dropped on the southwest. Movement on the Padre Juan Fault, on the southern end of the mapped units, has lifted the Pico Formation forming a graben in the middle. According to Nagle and Parker (1971), and Keller (1988) and others, this graben widens with depth.

Structurally, a north-south compression of sedimentary strata, which began in Pleistocene time and continues to the present, caused crustal shortening and warping of the sedimentary fabric into the mostly east-west trending series of anticlinal/synclinal folds present in the study area (Keller, 1988, from Nagle and Parker, 1971; Yeats, 1983; Namson, 1987). As deformation continued, large, north- and south-dipping reverse faults were formed offsetting the rock formations. The compression also affected sediments north of Red Mountain Fault within the Pitas Point Quadrangle and beyond. The largest structural elements in the Pitas Point Quadrangle are the Rincon Anticline and the Red Mountain Fault. In the Pitas Point Quadrangle, the north-dipping Red Mountain Fault and the south-dipping Padre Juan Fault (also known as the Javon Canyon Fault at the surface) divide the area surrounding the Rincon Anticline, into three main blocks.

Since deposition, sedimentary rocks in this province have been complexly folded, faulted, and uplifted, during several periods of deformation and erosion. These folded strata contain numerous petroleum traps. The hilly, middle and southern onshore areas are developed as oil fields (Rincon, Padre Juan, and San Miguelito fields), as are some of the near-shore areas.

Structurally, the area is undergoing deformation including rapid uplift in the recent past, which has pushed up the sedimentary rocks and, concurrently, the Quaternary alluvial veneer to the current elevations. Estimates of the amount of compression and convergence vary from 23 mm/yr (Yeats, 1983) to about 27 mm/yr (Namson, 1987). The intense and ongoing deformation that created the steep limbed folds and faults also created a southward arched curve of structural grain in the middle of the quadrangle. The Rincon Anticline, the largest fold in the Pitas Point Quadrangle, is present offshore at Punta Gorda, and trends southeast onshore. This anticline then turns eastward, and becomes the Ventura Avenue Anticline.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Pitas Point Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database.

Recent CGS field studies in the Pitas Point Quadrangle indicate failures on many of the slopes of softer uplifted sediments, particularly the Tertiary shale units, and within the Pico Formation. Most slope failures found during this investigation were classified as rockslides and/or debris slides and flows. They range in depth from shallow to deep, and while most appeared dormant, there are many active slides in the area. Most oilfield areas within the quadrangle exhibit ongoing remediation of roads and other cultural features due to landslide activity. Subsequently, some of the landslide features have been obliterated, while others are made more apparent. Alluvial deposits in the canyon bottoms are relatively shallow, due in part to the steep canyon walls and large watershed areas, which carry away some of the debris that might be expected to be deposited during periods of increased flow. Landslides, debris slides and flows, and earth slides and flows are very abundant within the Pitas Point Quadrangle. The so-called “La Conchita” landslide of March 4, 1995 destroyed nine dwellings (Bedrossian, 1996, p. 116). Since the 1995 La Conchita landslide, areas within the Pitas Point Quadrangle have continued to experience changes due to landsliding and related slope-failure phenomena. Changes include those associated with grading, seasonal erosion, and ground surface degradation. Based on a review of 1998 USGS aerial photographs and field observations by CGS geologists, several roads within the oil fields have been re-graded and subsequently have failed due to landslides and to debris slides and/or flows. Field observation also indicates that some of the roads have since been repaired and some of the landslides continue to displace roads and other man-made features.

In general, landslides are abundant in the Pitas Point Quadrangle where the weak sedimentary rocks have been deformed by several episodes of folding, faulting and tectonic uplift. Landslides in the area include: major complex landslides and debris flows, minor surficial failures resulting from soil and rock creep and/or rock fall, and major and minor soil and debris slumps and flows.

Several large and relatively old and deeply eroded, rotational/translational landslides are found in the northeastern corner of the quadrangle. The presence of marine terraces covered by debris that appears to be flowing slowly, adds to the difficulty of landslide identification. Older and younger rock falls, and landslides, occur on the steep faces of some of the coastal terrace bluffs (for example, La Conchita, 1995). Rock falls, landslides, and debris slides and flows involving bedding planes and fractured bedrock, occur on both shallow and steep slopes within the quadrangle. Debris flows are common on moderate to steep slopes. Most individual debris-flow tracks and deposits were not mapped for this study, although some of the larger ones were. Areal distribution of landslides identified in the map area is shown on Plate 2.1

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Pitas Point Quadrangle geologic map were obtained from the County of Ventura Public Works Agency (see Appendix A). The locations of rock and soil samples taken for shear testing within the Pitas Point Quadrangle are shown on Plate 2.1. Thirty-one shear tests were conducted on 17 borehole or trench samples. For the Pitas Point Quadrangle, shear test data from adjoining quadrangles, primarily the Ventura Quadrangle, were used to augment the data for several geologic formations for which little or no information was available.

Shear strength data gathered from the above source were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups (Table 2.2) in the map area, a single shear strength value was assigned and used in our slope stability analyses. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

The Sespe Formation was subdivided further, as described below.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The Sespe Formation, which contains interbedded sandstone and shale, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of bedding of favorable and adverse orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Sespe Formation are included in Table 2.1.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

Within the Pitas Point Quadrangle, no shear strength test data of landslide slip surface materials were available. However, three shear strength tests were available from the adjacent Ventura Quadrangle. These values were used to characterize the strength of existing landslides in the Pitas Point Quadrangle. The results are summarized in Table 2.1.

SHEAR STRENGTH GROUPS FOR THE PITAS POINT QUADRANGLE							
	Formation Name	Number Tests Pitas Point/Ventura	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Qs	1/0	34/34				
	Tm	8/0	35/34	35/35	340/200	Tvq	35
	Tpsc	2/0	34/34				
GROUP 2	Qoa	11/16	29/29	29/30	326/240	Tsp(fbc), Tr,	
	Qa	3/13	29/30			QTpm, af,	30
						Tps, Tsq	
GROUP 3	Tp	6/8	23/22	23/22	356/305	Tsp(abc),	
						Tml, Tpr,	22
						Qog	
GROUP 4						Qls	9

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
Formations for strength groups from Dibblee (1988).

Table 2.1. Summary of the Shear Strength Statistics for the Pitas Point Quadrangle.

SHEAR STRENGTH GROUPS FOR THE PITAS POINT QUADRANGLE			
GROUP 1	GROUP 2	GROUP 3	GROUP 4
Qs, Tm, Tpsc, Tvq	Qoa, Qa, Tsp(fbc), Tr, QTpm, af, Tps, Tsq	Tp,Tsp(abc), Tml, Tpr, Qog	Qls

Table 2.2. Summary of Shear Strength Groups for the Pitas Point Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Pitas Point election of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	3.9 to 7.1 km
PGA:	0.54 to 0.72 g

The strong-motion record selected for the slope stability analysis in the Pitas Point Quadrangle was the Corralitos record from the 1989 magnitude 6.9 (M_w) Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.086, 0.133 and 0.234g, respectively. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Pitas Point Quadrangle.

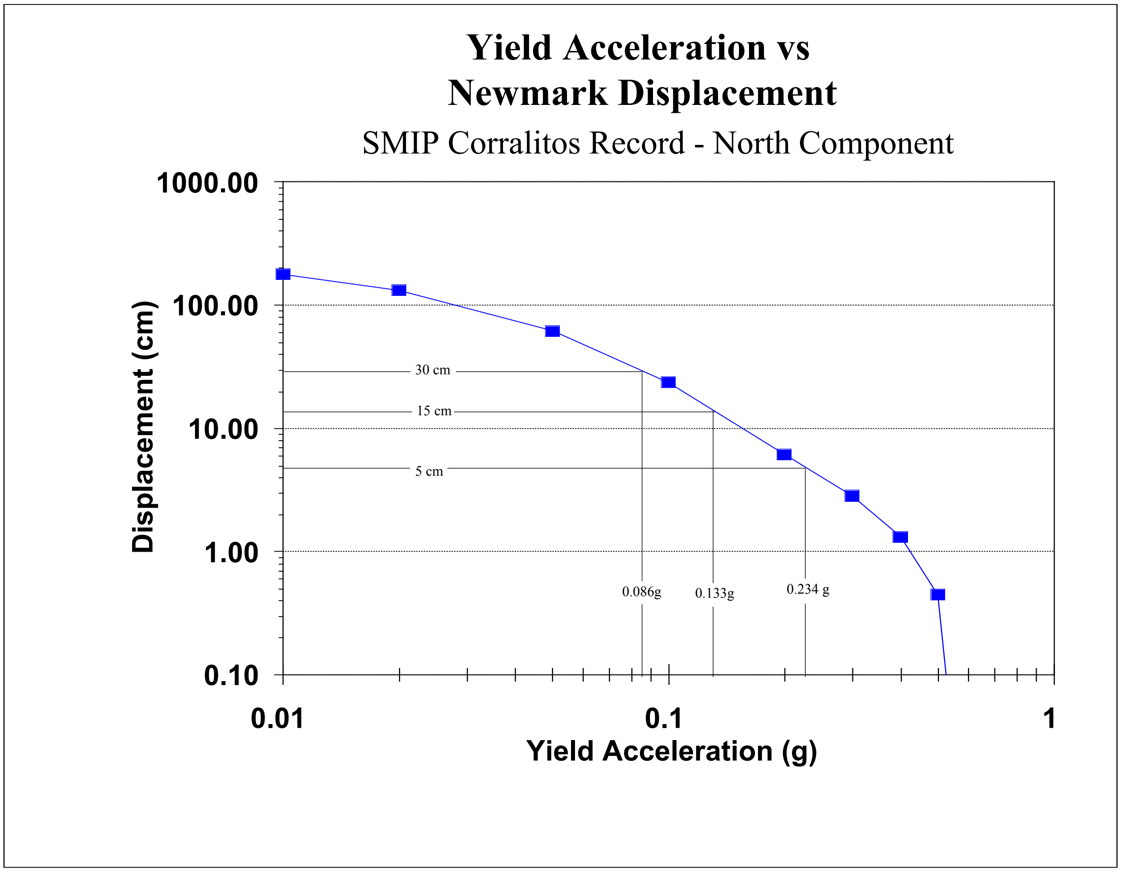

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Corralitos Record from the 1989 Loma Prieta Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.086g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.133g and 0.086g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.234g and 0.133g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.234g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

PITAS POINT QUADRANGLE HAZARD POTENTIAL MATRIX											
		SLOPE CATEGORY (% SLOPE)									
Geologic Material Group	Average PHI	I	II	III	IV	V	VI	VII	VII	IX	X
		0-2	3-7	8-17	18-25	26-33	34-43	44-47	48-54	55-59	>60
1	35	VL	VL	VL	VL	VL	VL	L	L	M	H
2	30	VL	VL	VL	VL	VL	L	M	H	H	H
3	22	VL	VL	VL	L	M	H	H	H	H	H
4	9	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Pitas Point Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Material Strength Group 4 is included for all slope gradient categories. (Note: Geologic Strength Group 4 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 3 is included for all slopes steeper than 17 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 33 percent.

4. Geologic Strength Group 1 is included for all slopes steeper than 43 percent.

This results in approximately 75 percent (7 square miles) of the land portion of the Pitas Point Quadrangle lying within the earthquake-induced landslide hazard zone.

ACKNOWLEDGMENTS

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA*

SOURCE	NUMBER OF TESTS SELECTED
Pitas Point Quadrangle **County of Ventura Public Works Agency**	**31**
Ventura Quadrangle	**86**
Total Number of Shear Tests	**117**

*Due to the limited rock strength shear test data available for the Pitas Point Quadrangle, data from the adjacent Ventura Quadrangle were combined to expand data sets for both quadrangles. See Seismic Hazard Zone Report 067 for the Ventura Quadrangle.

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Pitas Point 7.5-Minute Quadrangle, Ventura County, California

By

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California Geological Survey
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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

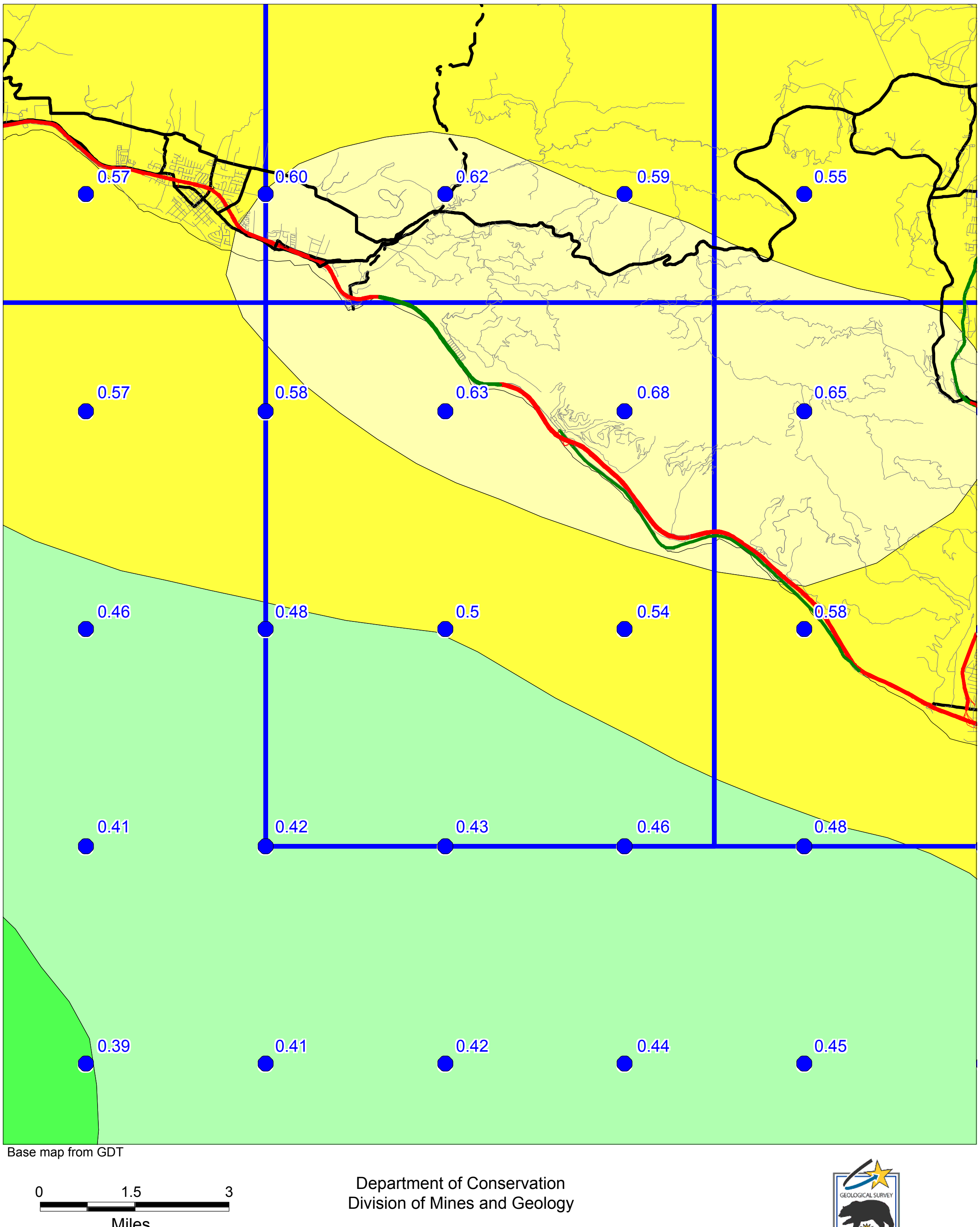
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

PITAS POINT 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

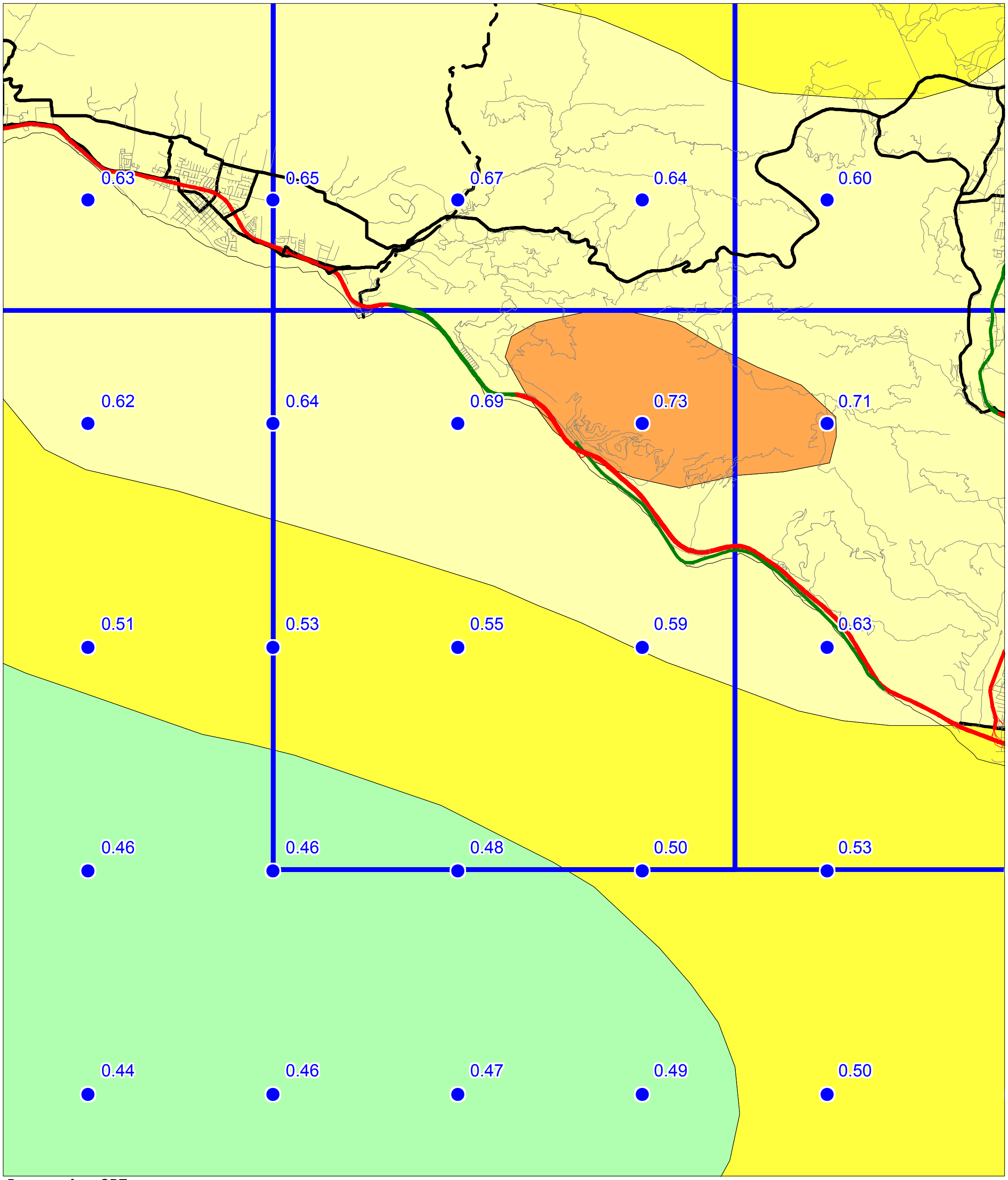
Figure 3.1

pitas point 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

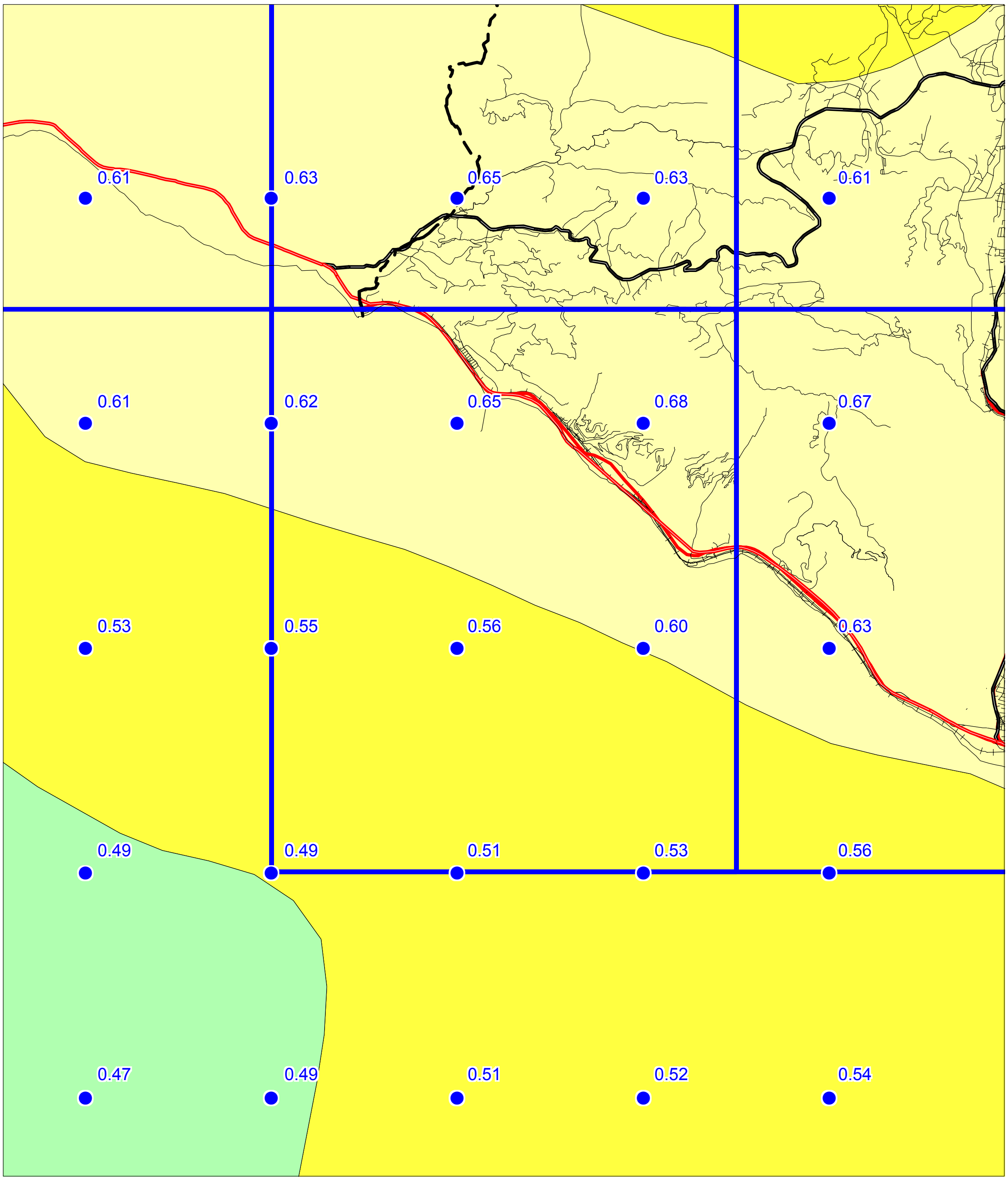
Figure 3.2

PITAS POINT 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

PITAS POINT 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

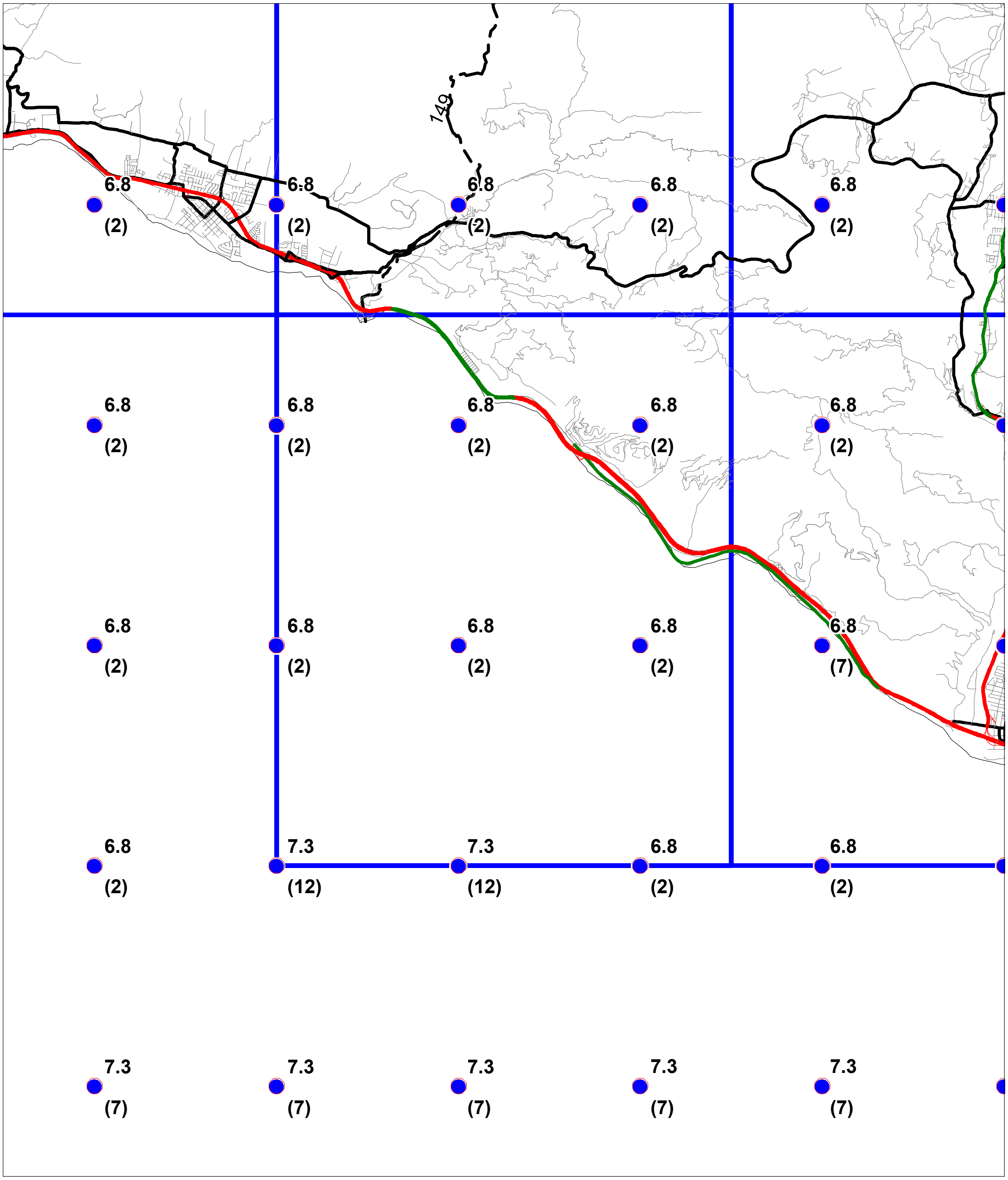
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map from GDT

0 1.5 3

Miles

Department of Conservation

California Geological Survey

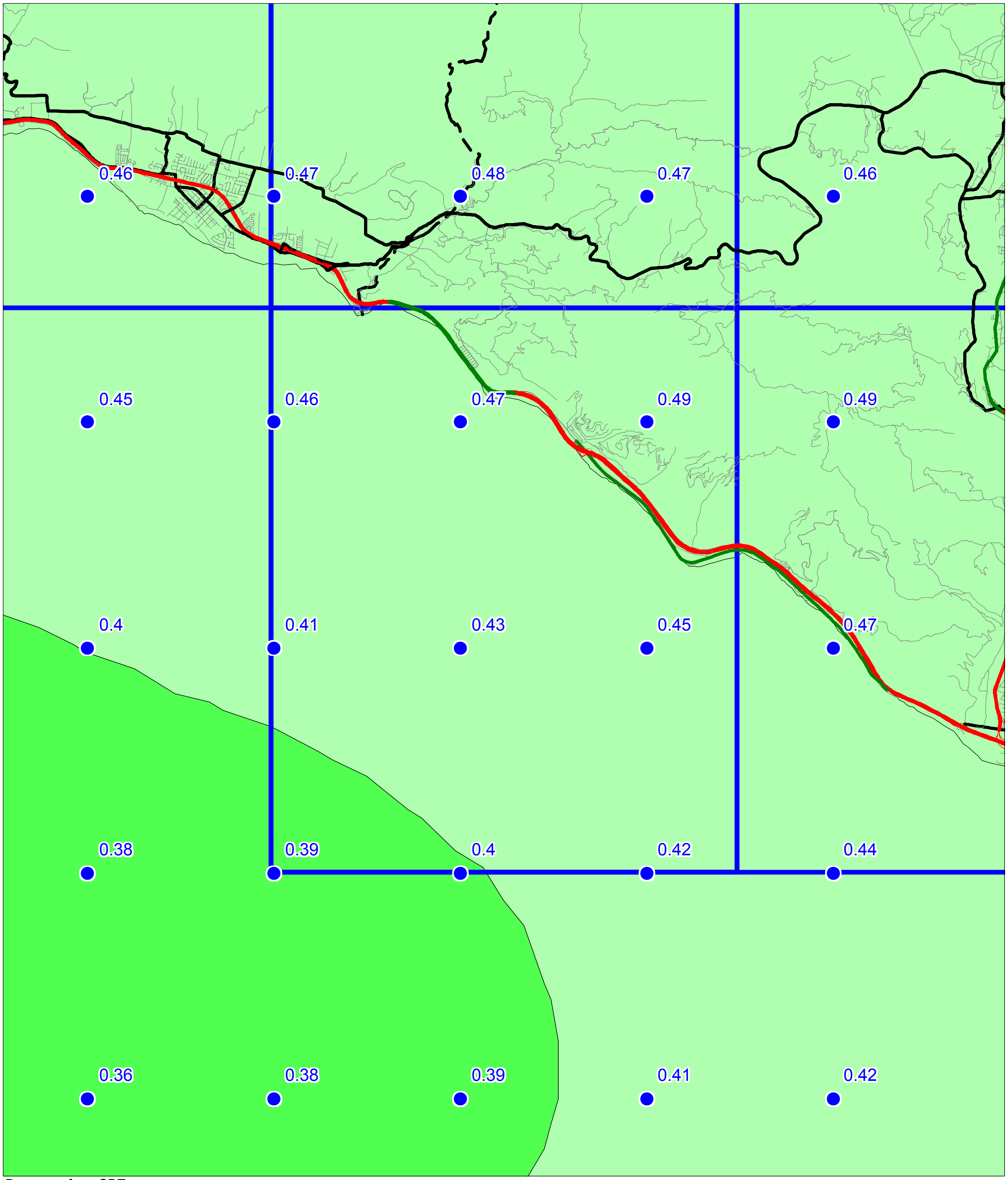
Figure 3.4

PITAS POINT 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

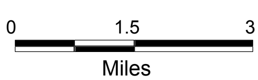
10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

2001

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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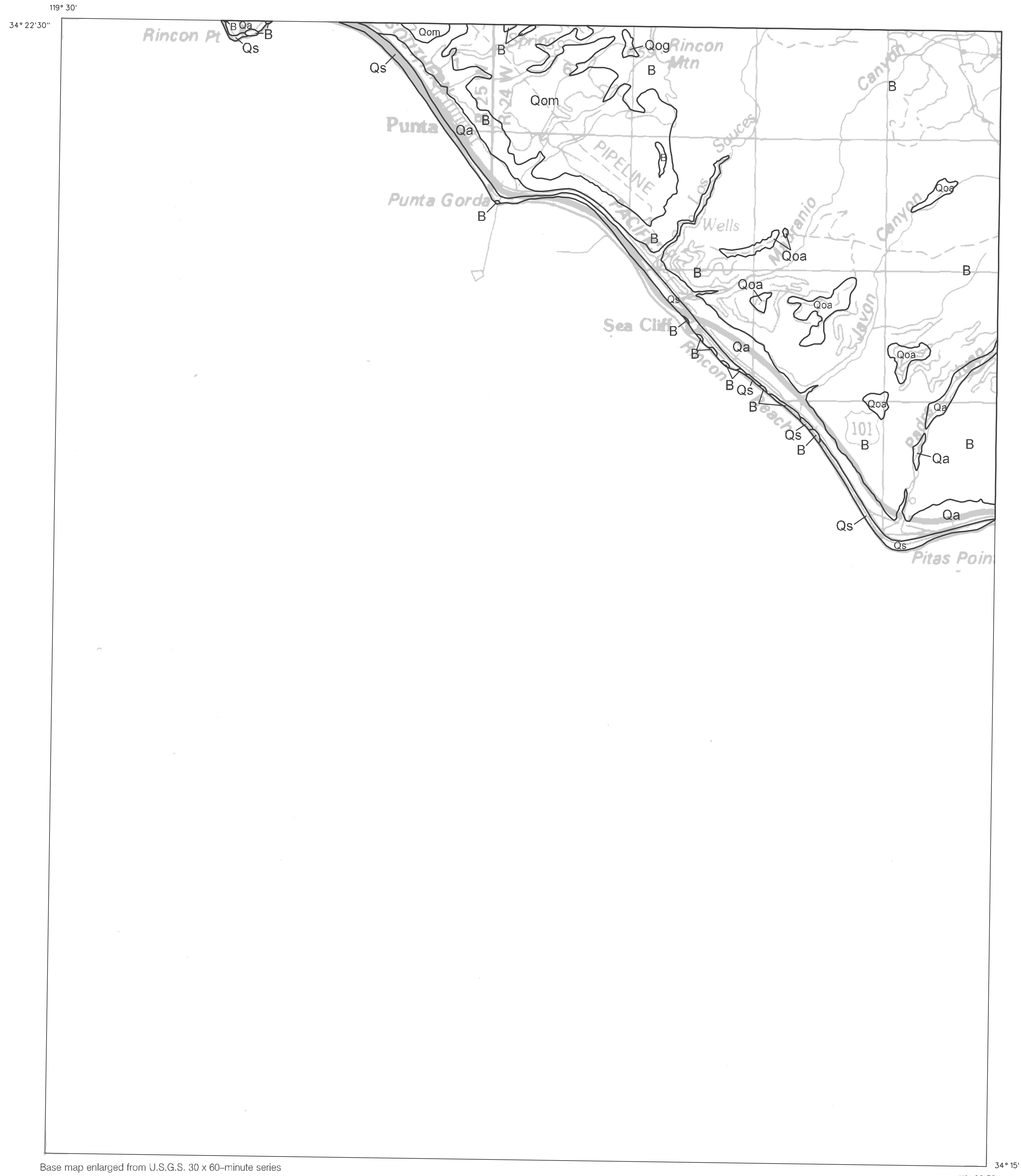
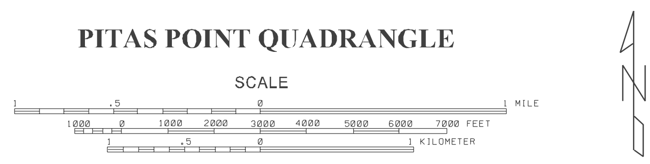


Base map enlarged from U.S.G.S. 30 x 60–minute series

PITAS POINT QUADRANGLE

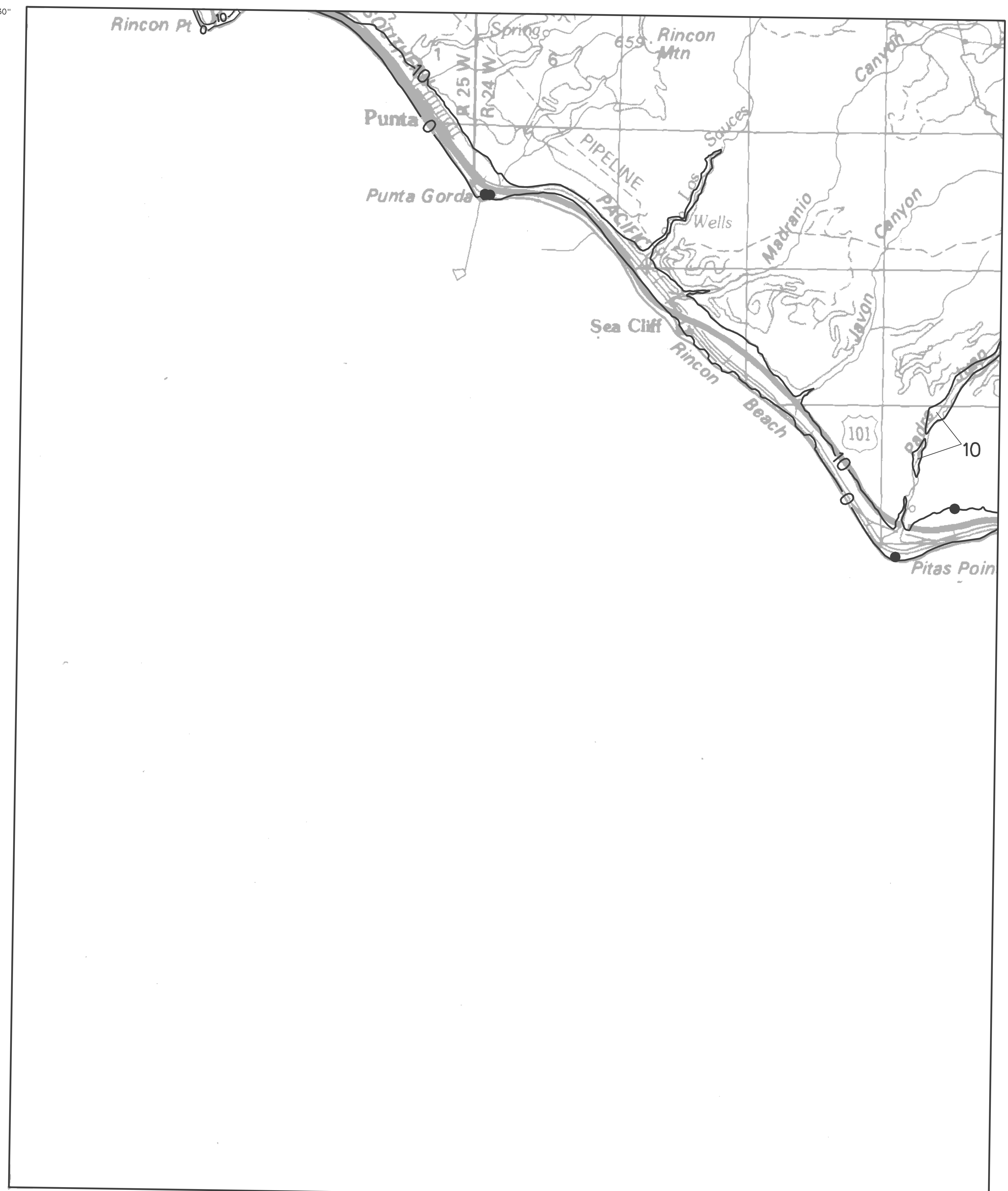


B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Pitas Point 7.5-minute Quadrangle *(From Dibblee, 1998).*

119° 30'
34° 22'30"



Base map enlarged from U.S.G.S. 30 x 60-minute series

34° 15'
119° 22'30"

PITAS POINT QUADRANGLE

SCALE

1 MILE | .5 | 0 | 1 MILE
1000 | 0 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 FEET
1 | .5 | 0 | 1 KILOMETER

N

50 — Depth to ground water, in feet

Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Pitas Point 7.5-minute Quadrangle, California

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DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR

Pitas Point Quadrangle Plate 2.1
SEISMIC HAZARD ZONE REPORT 073

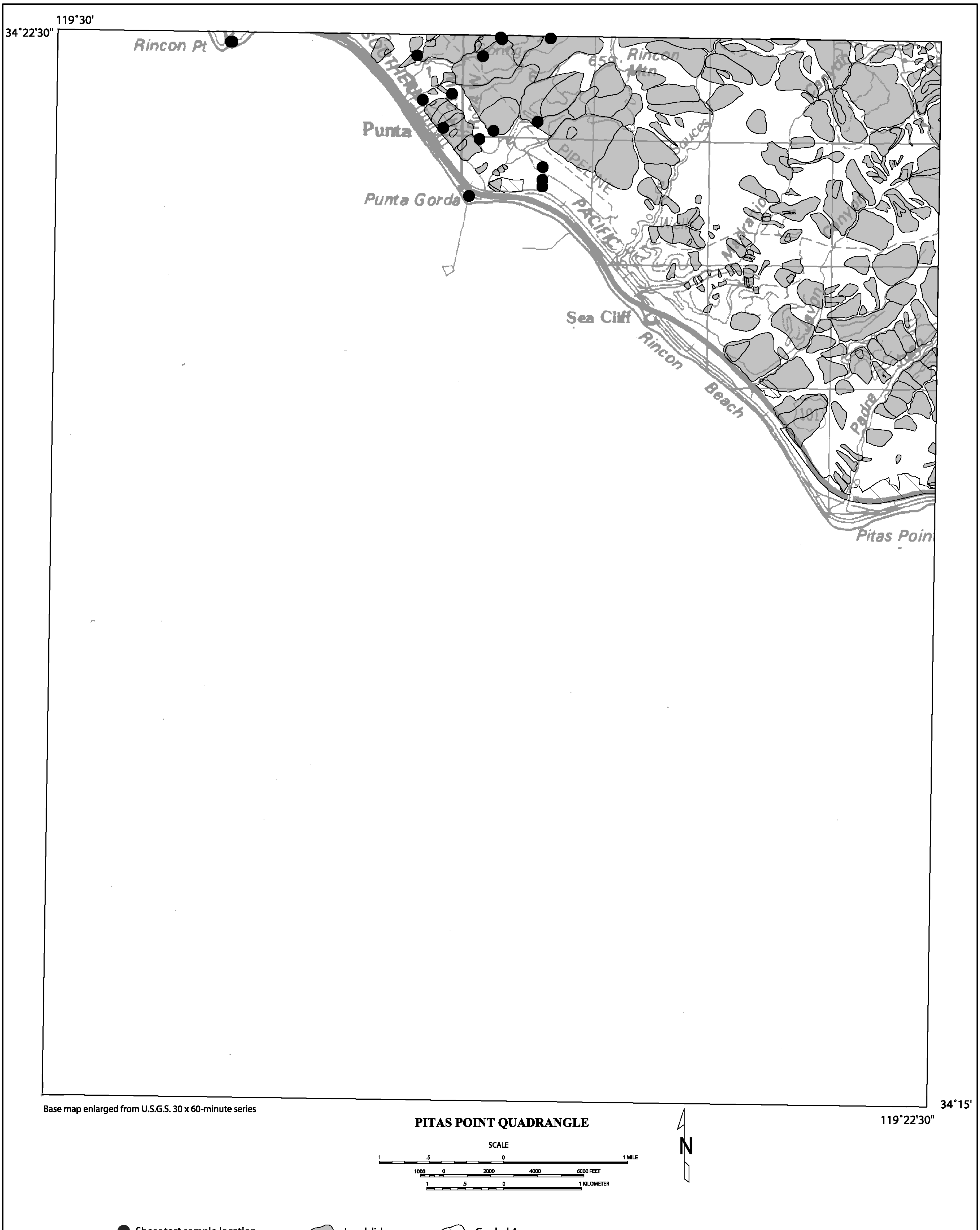

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Pitas Point 7.5-minute Quadrangle, California.